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JP 620007019 A **US 6318863 B**

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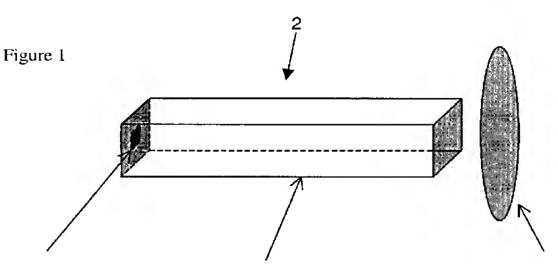
Other: **Online: EPODOC, JAPIO, TXTE, WPI**

(54) Abstract Title: **Structured light generator**

(57) A structured light generator (2) for illuminating a scene with a two dimensional pattern of intensity, such as an array of distinct spots or array of lines has a light source (4) such as an LED arranged to illuminate the input face of a light guide such as kaleidoscope (6). The light guide is a solid or hollow tube, generally of a constant, regular cross section which is arranged to create multiple images of the light source. Projection optics such as lens (8) is arranged to project the array towards the scene. The structured light generator (2) may be used with a range finding apparatus such as an imaging range finding system.

Figure 1



At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

This print takes account of replacement documents submitted after the date of filing to enable the application to comply with the formal requirements of the Patents Rules 1995

Original Printed on Recycled Paper

GB 2 395 289 A

Figure 1

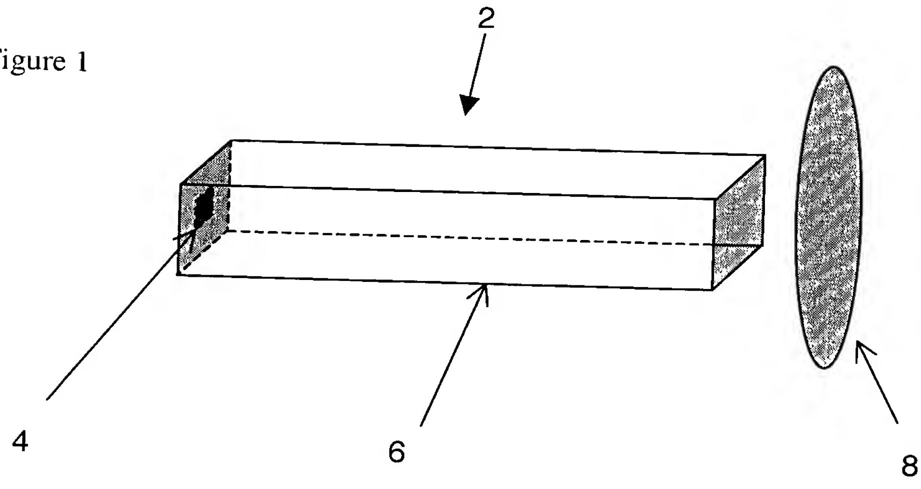


Figure 2

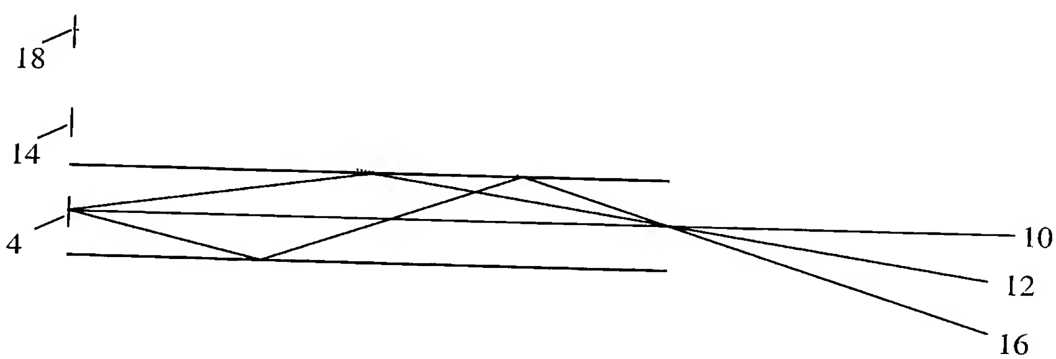


Figure 3

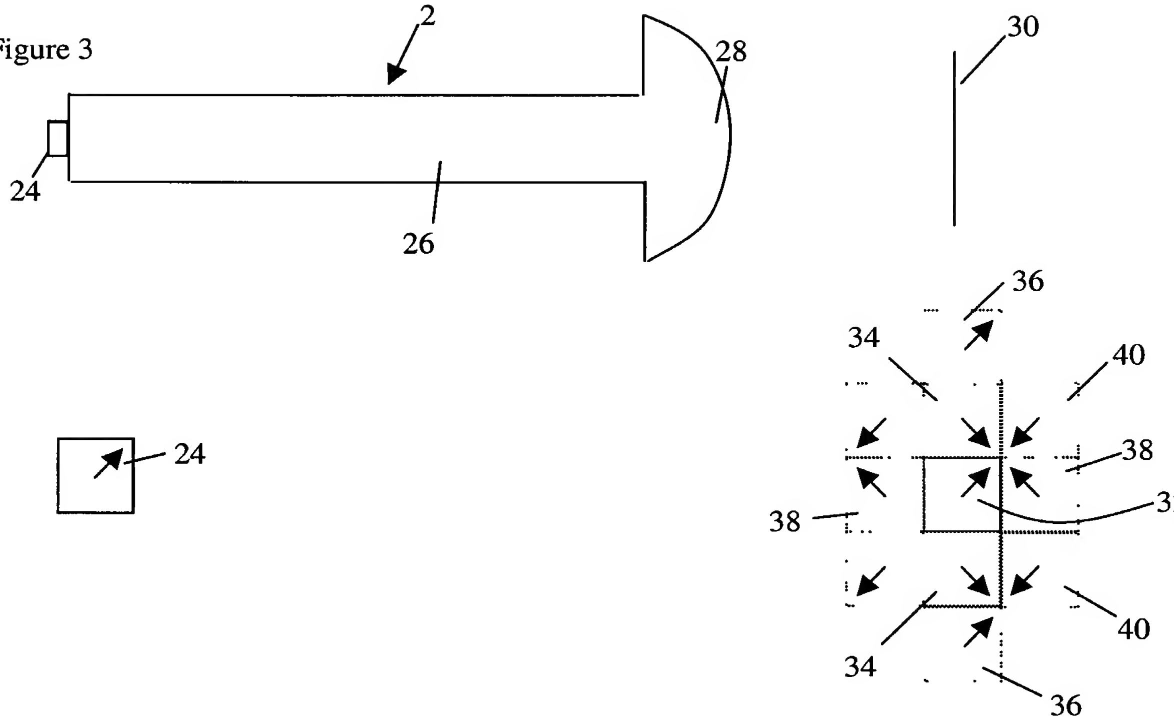


Figure 4

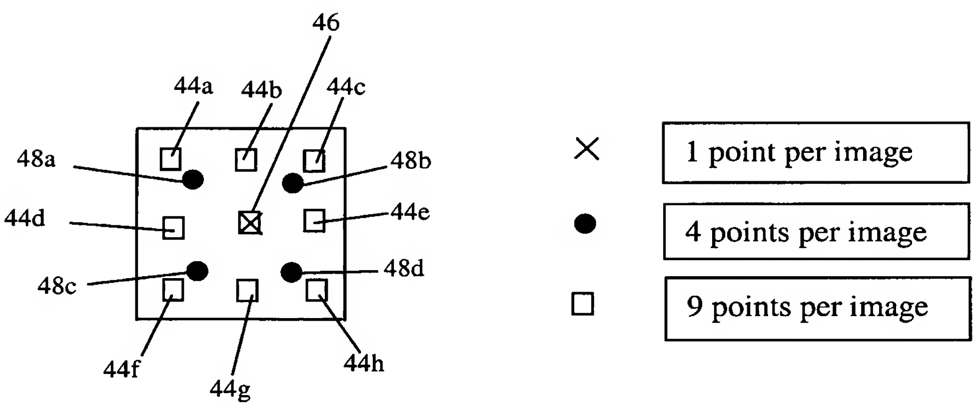


Figure 5

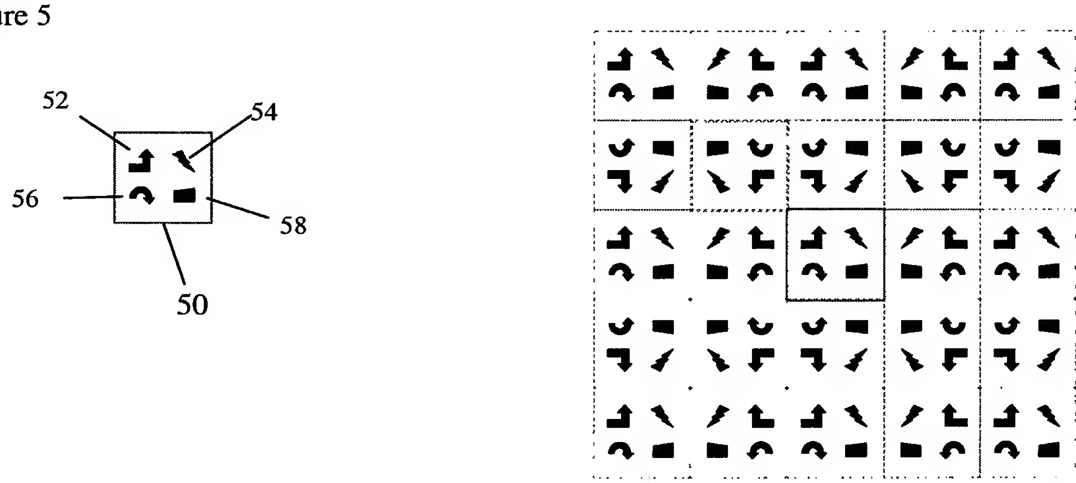


Figure 6

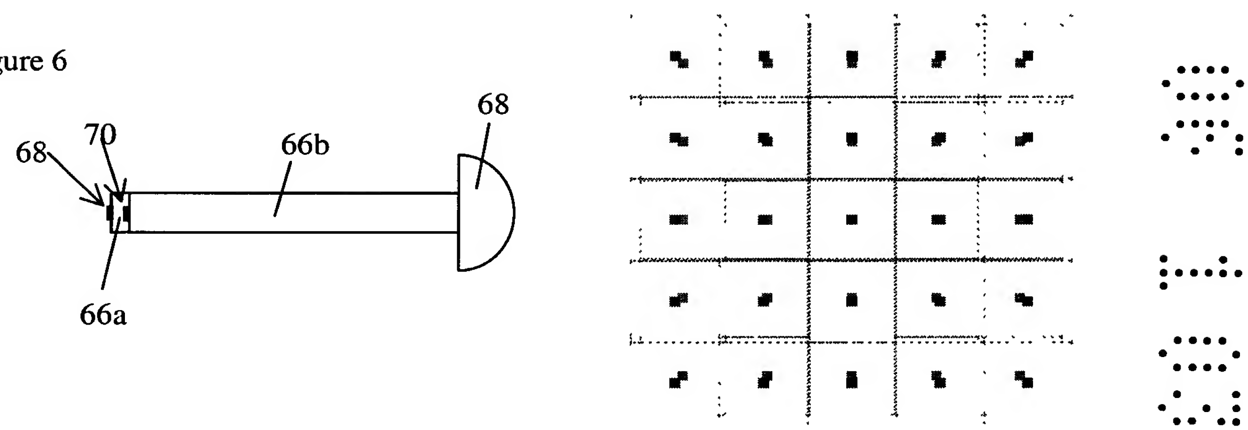


Figure 7

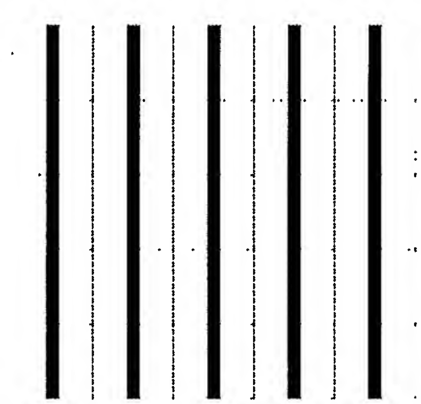
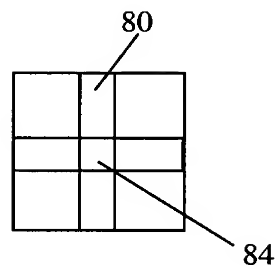
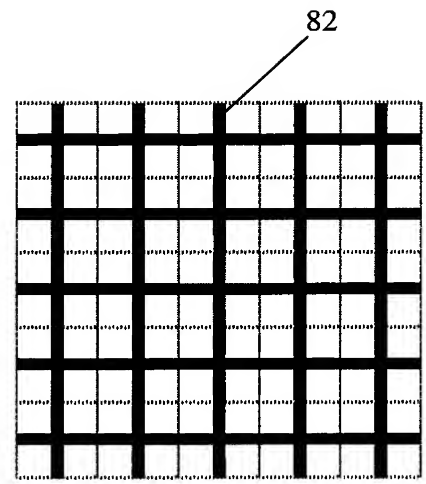


Figure 8





Structured Light Generator

This invention relates to a structured light generator for illuminating a scene such as might be used with a range finding apparatus such as an imaging range finding system.

Imaging range finding systems often illuminate a scene and image the light reflected from the scene to determine range information.

One known system, a so called triangulation system, uses a source arranged to illuminate a scene with a beam of light such that a spot appears in the scene. A detector is oriented in a predetermined fashion with respect to the source such that the position of the spot of light in the scene reveals range information. The beam of light may be scanned in both azimuth and elevation across the scene to generate range information from across the whole scene. In some systems the beam of light may be a linear beam such that one dimensional range information is gathered simultaneously and the linear beam scanned in a perpendicular direction to gain range information in the other dimension.

Illumination systems of this sort often use laser systems. Laser systems may have safety implications and require complicated and relatively expensive scanning mechanisms. Lasers are also relatively high power sources.

Another type of illumination system is described in US patent 6,377,353. Here a structured light generator is described which comprises a light source arranged in front of a patterned slide which has an array of apertures therein. Light from the sources only passes through the apertures and projects an array of spots onto the scene. The range information in this apparatus is determined by analysing the size and shape of the spots formed.

This type of illumination system blocks a proportion of the light generated by the source however and as such requires a relatively high power source to generate the illumination required. Further the depth of field of the illuminations system is somewhat limited and discrimination is difficult at low ranges.

It is therefore an object of the invention to provide a structured light source that mitigates at least some of the above mentioned disadvantages. As used in this specification the term structured light generator shall be taken to mean a source which projects a plurality of distinct areas of light towards a scene.

Therefore, according to the present invention there is provided a structured light generator for illuminating a scene comprising a light source arranged to illuminate part of the input face of a light guide, the light guide comprising a tube having substantially reflective sides and being arranged together with projection optics so as to project an array of images of the light source towards the scene.

The light guide in effect operates as a kaleidoscope. Light from the source is reflected from the sides of the tube and can undergo a number of reflection paths within the tube. The result is that multiple images of the light source are produced and projected onto the scene. Thus the scene is illuminated with an array of images of the light source. Where the source is a simple light emitting diode the scene is therefore illuminated with an array of spots of light.

The light guide comprises a tube with substantially reflective walls. Preferably the tube has a constant cross section which is conveniently a regular polygon. Having a regular cross section means that the array of images of the light source will also be regular which is advantageous for ranging applications. A regular array of spots ensures that the scene is illuminated in a known manner and will ease discrimination of spots for ranging purposes. A square section tube is most preferred.

The tube may comprise a hollow tube having reflective internal surfaces, i.e. mirrored internal walls. Alternatively the tube may be fabricated from a solid material and arranged such that a substantial amount of light incident at an interface between the material of the tube and surrounding material undergoes total internal reflection. The tube material may be either coated in a coating with a suitable refractive index or designed to operate in air, in which case the refractive index of the light guide material should be such that total internal reflection occurs at the material air interface.

Using a tube like this as a light guide results in multiple images of the light source being generated which can be projected to the scene. The light guide is easy to manufacture and assemble and couples the majority of the light from the source to the scene. Thus low power sources such as light emitting diodes can be used. As the exit aperture can be small the apparatus also has a large depth of field which makes it useful for ranging applications which require spots projected that are separated over a wide range of distances.

The projection optics may comprise a projection lens. The projection lens may be located adjacent the output face of the light guide. In some embodiments where the light guide is solid the lens may be integral to the light guide, i.e. the tube may be shaped at the output face to form a lens.

Preferably the projection optics are adapted so as to focus the projected array at relatively large distances. This provides a sharp image at large distances and a blurred image at closer distances. The amount of blurring can give some coarse range information which can be useful for ranging applications. The discrimination is improved if the light source has a non circular shape.

For ranging applications it is necessary for the range detector to be able to detect a spot in the scene and know unambiguously what spot in the projected array it corresponds to. Providing coarse range information in the focussing can help remove some ambiguity. Therefore the projection optics are preferably adapted to provide a substantially focussed image at a first distance and a substantially unfocussed image at a second distance, the first and second distance being within the expected range of operation of the apparatus. As mentioned the first distance may be larger than the second distance.

In order to further remove ambiguity the light source may have a shape which is not symmetric about the axes of reflection of the light guide. If the light source is not symmetrical about the axis of reflection the light source will be different to its mirror image. Adjacent spots in the projected array are mirror images and so shaping the light source in this manner would allow discrimination between adjacent spots.

The apparatus may comprise more than one light source, each light source arranged to illuminate part of the input face of the light guide. Using more than one light source can improve the spot resolution in the scene. Preferably the more than one light sources are arranged in a regular pattern. The light sources may be arranged such that different arrangements of sources can be used to provide differing spot densities. For instance a single source could be located in the centre of the input face of the light guide to provide a certain spot density. A separate two by two array of sources could also be arranged on the input face and could be used instead of the central source to provide an increased spot density.

Where more than one light sources are used at least one light source could be arranged to emit light at a different wavelength to another light source. Using sources with different wavelengths means that the array of spots projected into a scene will have differing wavelengths, in effect the sources and hence corresponding spots will be different colours – although the skilled person will appreciate that the term colour is not meant to imply operation in the visible spectrum. Having varying colours will help remove ambiguity over which spot is which in the projected array.

Alternatively at least one light source could be shaped differently from another light source, preferably at least one light source having a shape that is not symmetric about a reflection axis of the light guide. Shaping the light sources again helps discriminate between spots in the array and having the shapes non symmetrical means that mirror images will be different, further improving discrimination as described above.

At least one light source could be located within the light guide, at a different depth to another light source. The angular separation of the projected array from a kaleidoscope is determined by the ratio of its length to its width as will be described later. Locating at least one light source within the kaleidoscope effectively shortens the effective length of light guide for that light source. Therefore the resulting pattern projected towards the scene will comprise more than one array of spots having different periods. The degree of overlap of the spot will therefore change with distance from the centre of the array which can be used to identify each spot uniquely.

The light source may be arranged to run from one side of the input face to another such that the structured light generator illuminates the scene with an array of lines. If a light source is used which is arranged to run from one side of the input face of the light guide to another in a direction orthogonal to a reflection axis the effect will be that a constant line is projected onto the scene which can be useful for some applications. In some embodiments it may be wished to illuminate the scene with intersecting lines. The points of intersection between the lines may be used for identification for ranging purposes in a similar manner to separated spots as described above. The points of intersection could then be used to locate the range to that point. That range information could then be used to allow ranging to any other point on the line allowing more detailed range information to be gathered. In some cases however is may be best to range to separate spots and then activate the lines in which case the light source may be adapted to illuminate the light guide so as to produce an array of lines or an array of separate spots.

The invention will now be described by way of example only with reference to the following drawings of which;

Figure 1 shows a structured light source according to the present invention,

Figure 2 illustrates how the structured light source projects multiple spots,

Figure 3 shows another embodiment of a structured light generator according to the present invention,

Figure 4 shows the input face of a light guide of the present invention having a plurality of light sources,

Figure 5 shows the input face of a light guide of the present invention having a plurality of shaped light sources and part of the pattern projected toward the scene,

Figure 6 shows a structured light source having two light sources arranged at different depths and a part of the pattern projected towards the scene,

Figure 7 shows the output pattern of a structured light source arranged to illuminate the scene with a plurality of lines, and

Figure 8 illustrates the input face and output pattern of a structured light source arranged to illuminate the scene with an array of intersecting lines.

A structured light source generally indicated 2 according to the present invention is shown in figure 1. A light source 4 is located adjacent an input face of a kaleidoscope 6. At the other end is located a simple projection lens 8. The projection lens is shown spaced from the kaleidoscope for the purposes of clarity but would generally be located adjacent the output face of the kaleidoscope.

The light source 4 is an infrared emitting light emitting diode (LED). Infrared is useful for ranging applications as the array of projected spots need not interfere with a visual image being acquired and infrared LEDs and detectors are reasonably inexpensive. However the skilled person would appreciate that other wavelengths and other light sources could be used for other applications without departing from the spirit of the invention.

The kaleidoscope is a hollow tube with internally reflective walls. The kaleidoscope could be made from any material with suitable rigidity and the internal walls coated with suitable dielectric coatings. However the skilled person would appreciate that the kaleidoscope could comprise a solid bar. Any material which is transparent at the wavelength of operation of the LED would suffice, such as clear optical glass. The material would need to be arranged such that at the interface between the kaleidoscope and the surrounding air the light is totally internally reflected within the kaleidoscope. Where high projection angles are required this could require the kaleidoscope material to be cladded in a reflective material. An ideal kaleidoscope would have perfectly rectilinear walls with 100% reflectivity. It should be noted that a hollow kaleidoscope may not have an input or output face as such but the entrance and exit to the hollow kaleidoscope should be regarded as the face for the purposes of this specification.

The effect of the kaleidoscope tube is such that multiple images of the LED can be seen at the output end of the kaleidoscope. The principle is illustrated with reference to figure 2. Light from the LED 4 may be transmitted directly along the kaleidoscope undergoing no reflection at all – path 10. Some light however will be reflected once and will follow path 12. Viewed from the end of the kaleidoscope this will result in a virtual source 14 being seen. Light undergoing two reflections would travel along path 16 resulting in another virtual source 18 being observed.

The dimensions of the device are tailored for the intended application. Imagine that the LED 4 emits light into a cone with a full angle of 90°. The number of spots viewed on either side of the centre, unreflected, spot will be equal to the kaleidoscope length divided by its width. The ratio of spot separation to spot size is determined by the ratio of kaleidoscope width to LED size. Thus a 200μm wide LED and a

kaleidoscope 30mm long by 1mm square will produce a square grid of 61 spots on a side separated by five times their width (when focussed).

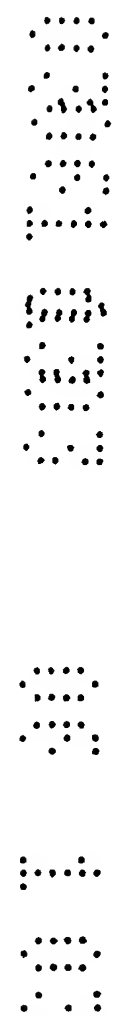
Projection lens 8 is a simple singlet lens arranged at the end of kaleidoscope and is chosen so as to project the array of images of the LED 4 onto the scene. The projection geometry again can be chosen according to the application and the depth of field required but a simple geometry is to place the array of spots at or close to the focal plane of the lens.

For some ranging applications it is advantageous that the spots are focussed at one likely range and unfocussed at another likely range. Where a structured light generator according to the present invention is used for ranging applications the scene is illuminated with a projected array of spots. A detector arranged to determine the location of spots in the scene can then work out the angle and hence range to that spot but only if it can determine exactly which spot is which. Determination of whether a spot were focussed or not would give a rough indication of range and hence remove some ambiguity about which spot was being considered. This discrimination can be improved if the LED is a particular shape, such as square so that an in-focus spot is also square. An unfocussed spot would be more circular in shape.

In one embodiment of the invention the light source is shaped so as to allow discrimination between adjacent spots. Where the light source is symmetric about the appropriate axes of reflection the spots produced by the system are effectively identical. However where a non symmetrically shaped source is used adjacent spots will be distinguishable mirror images of each other. The principle is illustrated in figure 3.

The structured light generator 2 comprises a solid tube of clear optical glass 26 having a square cross section. A shaped LED 24 is located at one face. The other end of tube 26 is shaped into a projection lens 28. Kaleidoscope 26 and lens 28 are therefore integral which increases optical efficiency and eases manufacturing as a single moulding step may be used. Alternatively a separate lens could be optically cemented to the end of a solid kaleidoscope with a plane output face.

For the purposes of illustration LED 24 is shown as an arrow pointing to one corner of the kaleidoscope, top right in this illustration. The image formed on a screen 30 is shown. A central image 32 of the LED is formed corresponding to an unreflected spot and again has the arrow pointing to the top right. Note that in actual fact a simple projection lens will project an inverted image and so the images formed would actually be inverted. However the images are shown not inverted for the purposes of explanation. The images 34 above and below the central spot have been once reflected and therefore are a mirror image about the x-axis, i.e. the arrow points to the bottom right. The next images 36 above or below however have been twice reflected about the x-axis and so are identical to the centre image. Similarly the images 38 to the left and right of the centre image have been once reflected with regard to the y-axis and so the arrow appears to point to the top left. The images 40 diagonally adjacent the centre spot have been reflected once about the x-axis and once about the y-axis and so the arrow appears to point to the bottom left. Thus the orientation of the arrow in the detected image gives an indication of which spot is being detected. This technique allows discrimination between adjacent spots but not subsequent spots.



Additionally or alternatively more than one light source could be used. The light sources could be used to give variable resolution in terms of spot density in the scene, or could be used to aid discrimination between spots, or both.

For example if more than one LED were used and each LED was a different colour the pattern projected towards the scene would have different coloured spots therein. The skilled person would appreciate that the term colour as used herein does not necessarily mean different wavelengths in the visible spectrum but merely that the LEDs have distinguishable wavelengths.

The arrangement of LEDs on the input face of the kaleidoscope effects the array of spots projected and a regular arrangement is preferred. To provide a regular array the LEDs should be regularly spaced from each other and the distance from the LED to the edge of the kaleidoscope should be half the separation between LEDs.

Figure 4 shows an arrangement of LEDs that can be used to give differing spot densities. Thirteen LEDs are arranged on the input face 42 of a square section

kaleidoscope. Nine of the LEDs, 46 & 44a – h, are arranged in a regular 3x3 square grid pattern with the middle LED 46 centred in the middle of the input face. The remaining four LEDs, 48a - d are arranged as they would be to give a regular 2x2 grid. The structured light generator can then be operated in three different modes. Either the central LED 46 could be operated on its own, this would project a regular array of spots as described above, or multiple LEDs could be operated. For instance, the four LEDs 48a-d arranged in the 2x2 arrangement could be illuminated to give an array with four times as many spots produced than with the centre LED 46 alone.

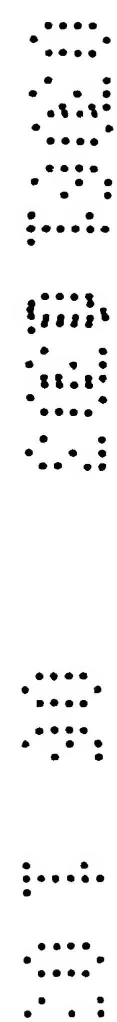
The different LED arrangements could be used at different ranges. When used to illuminate scenes where the targets are at close range the single LED may generate a sufficient number of spots for discrimination. At intermediate or longer ranges however the spot density may drop below an acceptable level, in which case either the 2x2 or 3x3 array could be used to increase the spot density. As mentioned the LEDs could be different colours to improve discrimination between different spots.

Where multiple sources are used appropriate choice of shape or colour of the sources can give further discrimination. This is illustrated with respect to figure 5. Here a 2x2 array of differently shaped sources, 52, 54, 56, 58 is illustrated along with a portion of the pattern produced. One can think of the resultant pattern formed as a tiled array of images of the input face 50 of the kaleidoscope with each adjacent tile being a mirror image of its neighbour about the appropriate axis. Looking just in the x-axis then the array will be built up by spots corresponding to LEDs 52 and 54 and followed by spots corresponding to their mirror images. The resultant pattern means that each spot is different from its next three nearest neighbours in each direction and ambiguity over which spot is being observed by a detector would be reduced.

Where multiple sources are used the sources may be arranged to be switched on and off independently to further aid in discrimination. For instance several LEDs could be used, arranged as described above, with each LED being activated in turn. Alternatively the array could generally operate with all LEDs illuminated but in response to a control signal from a detector which suggests some ambiguity could be used to activate or deactivate some LEDs accordingly.

In a further embodiment lights sources are arranged at different depths within the kaleidoscope. The angular separation of adjacent beams from the kaleidoscope depends upon the ratio between the length and width of the kaleidoscope as discussed above. Figure 6 shows a square section kaleidoscope 66 and projection lens 68. The kaleidoscope tube 66 is formed from two pieces of material 66a and 66b which may be clear optical glass or any other suitable material. A first LED 68 is located at the input face of the kaleidoscope as discussed above. A second LED 70 is located at a different depth within the kaleidoscope, between the two sections 66a and 66b of the kaleidoscope. The skilled person would be well aware of how to join the two sections 66a and 66b of kaleidoscope to ensure maximum efficiency and located the second LED 70 between the two sections.

The resulting pattern contains two grids with different periods with the grid corresponding to the second LED 70 partially obscuring the grid corresponding to the first LED 68. As can be seen the degree of separation between the two spots varies with distance from the centre spot. The degree of separation or offset of the two grids could then be used to identify the spots uniquely. The LEDs 68, 70 could be different colours as described above to improve discrimination.



Up until now the invention has been described with reference to producing discrete spots. The invention could be used to project continuous lines onto the scene however. A light source comprising a strip running from one side of the input face to the other and located centrally would produce an array of continuous lines as shown in figure 7. Similarly a square grid could be produced by use of a cross-shaped light source as shown in figure 8.

Referring to figure 8 a cross shaped LED 80 is arranged on the input face of the kaleidoscope. This result in the pattern of intersecting lines 82 shown being projected towards the scene. The points of intersection of the lines in the output pattern can be seen as separately identifiable spots. A detector could detect a point of intersection in the same way as it could detect a distinct spot as described above. However a detector having located the range to a point of intersection could then also determine range information to any other point along the intersecting line. Therefor in some applications projecting a grid of intersecting lines can be advantageous in that the

resolution of the ranging apparatus could be increased. Identification of a point of intersection may be less easy than identification of a unique spot however. In which case the cross shaped LED could comprise a separate central portion 84 which is independently operable. Activation of just the central portion 84 would result in an array of distinct spots being produced as described with reference to figures 1 and 2. Once the range to each spot had been determined the rest of LED 80 could be activated to provide additional detail for ranging.

CLAIMS

1. A structured light generator for illuminating a scene comprising a light source arranged to illuminate part of the input face of a light guide, the light guide comprising a tube having substantially reflective sides and being arranged together with projection optics so as to project an array of distinct images of the light source towards the scene.

2. A structured light generator as claimed in claim 1 wherein the light guide comprises a tube having a constant cross section.

3. A structured light source as claimed in claim 2 wherein the cross section of the tube is a regular polygon.

4. A structured light source as claimed in claim 3 wherein the tube has a square cross section.

5. A structured light source as claimed in any preceding claim wherein the light guide comprises a hollow tube having reflective internal surfaces.

6. A structured light source as claimed in any of claims 1 to 5 wherein the light guide comprises a tube of solid material adapted such that a substantial amount of light incident at an interface between the material of the tube and surrounding material undergoes total internal reflection.

7. A structured light source as claimed in any preceding claim wherein the projection optics comprises a projection lens.

8. A structured light source as claimed in claim 7 when dependent upon claim 6 wherein the tube of solid material is shaped at the output face to form the projection lens.

9. A structured light source as claimed in any preceding claim wherein the projection optics are preferably adapted to provide a substantially focussed

image at a first distance and a substantially unfocussed image at a second distance, the first and second distance being within the expected range of operation of the apparatus.

10. A structured light source as claimed in claim 9 wherein the first distance may be larger than the second distance.

11. A structured light source as claimed in any preceding claim wherein the light source has a non-circular shape.

12. A structured light source as claimed in claim 11 wherein the light source has a shape which is not symmetric about the axes of reflection of the light guide.

13. A structured light source as claimed in any preceding claim comprising more than one light source, each light source arranged to illuminate part of the input face of the light guide.

14. A structured light source as claimed in claim 13 wherein the light sources are arranged in a regular pattern.

15. A structured light source as claimed in claim 13 or claim 14 wherein the light sources are arranged such that different arrangements of sources can be used to provide differing spot densities.

16. A structured light source as claimed in any of claims 13 to 15 wherein at least one light source emits light at a different wavelength to another light source.

17. A structured light source as claimed in any of claims 13 to 16 wherein at least one light source is shaped differently from another light source.

18. A structured light source as claimed in any of claims 13 to 17 wherein at least one light source has a shape that is not symmetric about a reflection axis of the light guide.

19. A structured light source as claimed in any of claims 13 to 18 wherein at least one light source is located within the light guide, at a different depth to another light source.

20. A structured light source as claimed in any of claims 1 to 14 wherein the light source is arranged to run from one side of the input face to another such that the structured light generator illuminates the scene with an array of lines.

21. A structured light source as claimed in claim 20 wherein the light source is arranged relative to the light guide so as to illuminate the scene with intersecting lines.

22. A structured light source as claimed in claim 20 or claim 21 wherein the light source may is adapted so as to be capable of illuminate the light guide so as to produce either an array of lines or an array of separate spots.

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Application No:	GB 0226241.8	**Examiner:**	Conal Clynch
Claims searched:	1-22	**Date of search:**	31 March 2003

Patents Act 1977 : Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance	
X	1-2 & 5-6 & 11 at least	EP 0994342 A2	(SYSMEX CORP) see Figures 30-33 & paragraphs 6 & 88-95
X	1-2 & 5-6 & 11 at least	US 6318863 B	(I T R I) see Figure 11 & column 3 lines 25-31 & from column 10 line 65 to column 11 line 14
X	1-7 at least	FR 002585853 A	(AMORETTI) see the Figures & abstracts
X	1-7 at least	JP 620007019 A	(FUYO SANGYO) see Figures 1 & 3 & abstracts

Categories:

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^{V}:

Worldwide search of patent documents classified in the following areas of the IPC^{7}:

G01B
G01C

The following online and other databases have been used in the preparation of this search report:

Online: EPODOC, JAPIO, TXTE, WPI

PUB-NO: GB002395289A
DOCUMENT-IDENTIFIER: GB 2395289 A
TITLE: Structured light generator
PUBN-DATE: May 19, 2004

INVENTOR-INFORMATION:

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APPL-NO: GB00226241
APPL-DATE: November 11, 2002

PRIORITY-DATA: GB00226241A (November 11, 2002)

INT-CL (IPC): G01B011/25

EUR-CL (EPC): G01B011/25

ABSTRACT:

CHG DATE=20040525 STATUS=O>A structured light generator (2) for illuminating a scene with a two dimensional pattern of intensity, such as an array of distinct spots or array of lines has a light source (4) such as an LED arranged to illuminate the input face of a light guide such as kaleidoscope

(6). The light guide is a solid or hollow tube, generally of a constant, regular cross section which is arranged to create multiple images of the light source. Projection optics such as lens (8) is arranged to project the array towards the scene. The structured light generator (2) may be used with a range finding apparatus such as an imaging range finding system.